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Cancer Mortality Study of Employees at Lead Battery Plants and Lead Smelters, 1947–1995

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Background *This study has examined cancer mortality of a cohort of male U.S. workers exposed to lead.*

Methods *The cohort consisted of 4,518 workers at lead battery plants and 2,300 at lead smelters. Vital status was ascertained between 1947 and 1995. Site-specific cancer standardized mortality ratios (SMRs) and 95% confidence intervals (95% CIs), based on the mortality rates of the U.S. male population and adjusted for age and calendar time, were calculated for the total cohort as well as subcohorts stratified by various exposure parameters. In addition, a nested case-control study of stomach cancer (30 cases and 120 age-matched controls) was also conducted.*

Results *Mortality from all cancers was as expected (897 observed deaths, SMR = 103.8, 95% CI: 97.1–110.8). Mortality was significantly raised for stomach cancer (SMR = 147.4, 95% CI: 112.5–189.8), lung cancer (SMR = 116.4, 95% CI: 103.9–129.9), and cancer of the thyroid and other endocrine glands (SMR = 308.0, 95% CI: 133.0–606.8). There was a nonsignificant mortality deficit from kidney cancer (SMR = 63.6, 95% CI: 33.9–108.7). For bladder cancer, mortality was significantly lower than expected (SMR = 55.5, 95% CI: 31.7–90.1). Nonsignificant mortality deficits were also reported for cancer of the central nervous system (SMR = 74.8, 95% CI: 41.9–123.4) and lymphatic and hematopoietic cancer (SMR = 92.2, 95% CI: 72.4–115.7). Additional analyses by type of facility (lead battery plants vs. lead smelters), length of employment, latency, and period of hire were also performed. In the nested case-control study of stomach cancer, odds ratios were calculated for various exposure indices, and none was found to be elevated. Furthermore, no exposure–response relationship between lead exposure and stomach cancer was found in the nested case-control study.*

Conclusions *A significant mortality increase from stomach cancer was found. However, based on the analyses in the cohort study and the nested case-control study, the increase did not appear to be related to lead exposure. A small, but statistically significant mortality increase from lung cancer was also observed. The small increase, in the absence of an exposure–response relationship, could be the result of confounding due to smoking, and was not likely causally related to lead exposure. Although the significant increase in cancer of the thyroid and other endocrine glands appeared to be consistent with an occupational interpretation, the small number of deaths (8), the lack of information on potential confounding factors, and the lack of reporting of a similar increase in other studies underscore the need to view this finding with caution. No*

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increased mortality was found for kidney cancer, bladder cancer, cancer of the central nervous system, or lymphatic and hematopoietic cancer. Am. J. Ind. Med. 38:255–270, 2000.

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INTRODUCTION

Occupational exposure to lead has long been associated with lead poisoning, neuropathy, and renal diseases. Results on cancer from studies of workers exposed to lead, however, have been inconsistent, and the carcinogenic potential of lead is still unresolved. In an evaluation in 1987, the International Agency for Research on Cancer [IARC, 1987] classified lead and inorganic lead compounds as "possible human carcinogens" (Group 2B). The evaluation was based on "sufficient evidence for carcinogenicity in experimental animals but insufficient evidence for carcinogenicity in humans." In 1995, Fu and Boffetta at IARC performed a literature review and a meta-analysis of published data on cancer in workers exposed to lead [Fu and Boffetta, 1995]. Based on the literature review and meta-analysis, significant excess risks of stomach cancer and lung cancer were reported. The summary relative risks and 95% confidence intervals (95% CI) were 1.33 (95% CI: 1.18–1.49) for stomach cancer and 1.29 (95% CI: 1.10–1.50) for lung cancer, respectively. The authors concluded that the findings provided some evidence for an association between occupational exposure to lead and stomach cancer or lung cancer, but could not rule out the effects of confounders such as smoking and nonoccupational factors. Finally, Fu and Boffetta [1995] also reported excess risks for kidney cancer and bladder cancer, but suggested that the results could have been influenced by possible publication bias.

Included in the IARC [1987] evaluation and the Fu and Boffetta [1995] review was a cohort mortality study of U.S. lead battery and lead smelter workers [Cooper, 1976; Cooper and Gaffey, 1975; Cooper et al., 1985]. The cohort consisted of 4,519 male lead battery workers and 2,300 male lead smelter workers, who were employed at these facilities for at least 1 year between 1946 and 1970. Mortality of the cohort in the last update [Cooper et al., 1985] was ascertained through the end of 1980. With respect to cancer, mortality from stomach cancer and lung cancer was elevated. Among lead battery workers, the standardized mortality ratios (SMRs) and 95% CIs were 168 (95% CI: 116–235) for stomach cancer and 124 (95% CI: 102–150) for lung cancer, respectively. Among lead smelter workers, the SMRs and 95% CIs were 146 (95% CI: 67–278) for stomach cancer and 125 (95% CI: 89–169) for lung cancer, respectively. The authors commented that "Ethnicity, diet, alcohol and cigarette smoking could not be ruled out as possible confounding etiologic factors for the cancer deaths."

The present investigation was based on the data of the study of U.S. lead battery and lead smelter workers previously reported by Cooper et al. [1985]. The primary objectives of the present investigation were: (1) to update the vital status of the cohort, and (2) to analyze the updated site-specific cancer mortality data (particularly stomach cancer, lung cancer, kidney cancer, bladder cancer, cancer of the central nervous system, and lymphatic and hematopoietic cancer) in relation to employment pattern (type of facility, length of employment, and period of exposure). In addition, a nested case-control study of stomach cancer was also conducted. The primary objective of the case-control study was to analyze stomach cancer risk in relation to length and cumulative exposure to lead, based on a detailed classification of jobs by exposure category.

MATERIALS AND METHODS

The selection of the original cohort was based on a questionnaire survey in 1968. Questionnaires outlining the proposed study were sent to plants of member companies of the International Lead and Zinc Research Organization, the Lead Industry Association, or the Battery Council International. Information regarding operation history, workforce and personnel records was solicited. Of the 101 plants contacted, 84 indicated willingness to participate. Based on a consideration of operation history, the size of workforce, and the quality and availability of personnel records, 10 lead battery plants and six lead smelters (1 primary smelter, 2 secondary smelters, and 3 recycling plants) were chosen to be included in the study.

The cohort was defined as male workers with at least 1 year of employment between January 1, 1946 and December 31, 1970 at one of the selected facilities. A total of 4,519 lead battery employees and 2,300 lead smelter employees were included in the previous study. In the present update, the same cohort definition was used. However, based on a thorough review of the cohort data, one duplicate record was discovered among lead battery workers. In the present update, the duplicate record was removed, reducing the number of lead battery workers to 4,518.

The lead battery plants were located in California, Illinois, Pennsylvania (3 plants), Oregon, Texas (3 plants) and Wisconsin. Approximately 70% of the lead battery workers were employed at the three plants in Pennsylvania. The lead smelters were located in California (2 smelters), Indiana, Montana, Nebraska, and Pennsylvania. Approximately 35% of the lead smelter workers were employed at the Nebraska smelter, 23% at the Indiana smelter, and 19% at the Montana smelter.

In the last update of the study [Cooper et al., 1985], vital status was ascertained through December 31, 1980. In the present investigation, the vital status of the cohort was updated through December 31, 1995. The primary sources for vital status information in the update was the National Death Index (NDI) developed and maintained by the National Center for Health Statistics (NCHS). The Death Master File (DMF) maintained by the Social Security Administration (SSA) was also utilized. Dates and causes of death were obtained from either death certificates or NDI reports. Underlying causes of death were coded according to the International Classification of Diseases, 8th Revision (ICD-8).

In assembling the original cohort, employment histories through 1970 were collected, which included jobs, departments, and the corresponding effective dates. Subsequently, employment status (i.e., active, terminated, or retired) was updated through 1981. In the present investigation, employment status was not further updated. In other words, employment status for all cohort members was known through 1981 only.

As stated in the previous report by Cooper et al. [1985], there were no exposure data for the entire cohort. However, biological monitoring data were collected on some of the cohort members between 1947 and 1972, with the majority of the measurements made after 1960. In total, urinary lead measurements were available for 2,275 men, and blood lead concentrations for 1,863 men (Table I). There were 1,550 men with 10 or more urinary lead measurements. In this group of workers, the average urinary lead measurements were 129.7 µg/l (6.3 µmol/l) among lead battery workers and 173.2 µg/l (8.4 µmol/l) among lead smelter workers, respectively. In both groups, there were many individuals with average urinary lead levels above 200 µg/l (9.7 µmol/l). Among the 1,083 lead battery workers with three or more blood lead analyses, the average was 62.7 µg/100 g (3.0 µmol/l). For 254 lead smelter workers with at least three blood lead samples, the average blood lead level was 79.7 µg/100 g (3.9 µmol/l). However, for a number of lead battery or smelter workers, the average blood lead level was more than 100 µg/100 g (4.8 µmol/l).

In comparison, the current (1999) ACGIH Biological Exposure Index (BEI) for blood lead is 30 µg/100 ml. BEIs represent the levels of determinants which are most likely to be observed in specimens collected from a healthy worker who has been exposed to chemicals to the same extent as a worker with inhalation exposure to the threshold limit value

TABLE I. Urinary and Blood Lead Concentrations Among Lead Battery and Lead Smelter Workers, 1947–1972, USA

		Analysis of data based on workers with 10 or more samples					
				No. of workers whose averages exceeded			
Type of facility	Total no. of workers sampled	No. of workers	Average (µg/1)	150 µg/1	200 µg/1	250µg/1	300 µg/1
Urinary lead concentrations							
Battery	1286	1053	129.7	249	59	17	7
Smelter	989	497	173.2	289	164	70	27
Total	2275	1550	142.9	538	223	87	34

		Analysis of data based on workers with 3 or more samples					
				No. of workers whose averages exceeded			
Type of facility	Total no. of workers sampled	No. of workers	Average (µg/100 g)	40 µg/100 g	70 µg/100 g	80 µg/100 g	100 µg/100 g
Blood lead concentrations							
Battery	1326	1083	62.7	1009	278	102	24
Smelter	537	254	79.7	241	89	56	18
Total	1863	1337	64.0	1250	367	158	42

(TLV). Thus, historically the workers in the study were exposed to lead at levels far exceeding the current TLV of 0.05 mg/m^3.

No separate analysis of mortality was made for cohort members with biological monitoring data, since all the measurements were made between 1947 and 1972 and the majority after 1960. Thus, these measurements might not accurately reflect earlier exposure levels. Furthermore, many workers began employment prior to the implementation of the monitoring programs, and, therefore, might not have any recorded measurements. Recorded measurements presented in Table 1 served, however, as evidence that many cohort members had been exposed to lead in amounts far exceeding the current standards.

Site-specific cancer SMRs and corresponding 95% CIs were calculated for the entire cohort as well as for subcohorts stratified by type of facility (battery plants vs. smelters) and other exposure parameters. In the calculation of SMRs, the expected deaths were based on mortality rates of the male population in the U.S., and were adjusted for age and calendar time. Statistical analysis was performed using the Occupational Cohort Mortality Analysis Program (OCMAP) developed by the Department of Biostatistics at the University of Pittsburgh [Marsh et al., 1998].

In addition to the cohort study, a nested case-control study of stomach cancer among lead battery workers was also conducted. For practical reasons, the case-control study was limited to the largest participant in the study, which contributed half of the stomach cancer cases. It was felt that exposure assessment and collection of additional information would be more efficient if resources and efforts were limited to one single facility. The study consisted of 30 stomach cancer deaths at a lead battery plant in Philadelphia (the largest participant in the study) and 120 age-matched controls from the same facility. Job titles of these 150 workers were reviewed to determine the potential for lead exposure. Based on the review, jobs were classified by level of lead exposure into low, intermediate, and high categories (Appendix I). Several lead exposure indices were used in the case-control analysis: months of overall employment at the plant, months of employment in areas with intermediate or high lead exposures, and weighted cumulative exposure in months (1 = low, 2 = intermediate, 3 = high). Comparisons were made using total work histories prior to the deaths of the index cases, as well as exposures 10 (or 20) or more years prior to the deaths of the index cases. Means of various exposure indices were calculated and compared between the cases and controls. Odds ratios based on the Mantel–Haenszel χ^2 procedure were calculated for various exposure indices, and trend tests based on conditional logistic regression were performed for exposure–response analysis.

RESULTS

Table II presents some descriptive statistics of the cohort. Two-thirds of the cohort were lead battery workers. Close to 70% of the lead battery workers were employed for 20 years or longer, and 57% were hired prior to 1946. On the other hand, approximately 40% of lead smelter workers were employed for 20 years or longer, and 21% were hired before 1946. With respect to vital status, more than half of the cohort (N = 3,713) had been identified as having died. Death information was obtained from either death certificates or NDI reports for all workers identified to have died except for 18 decedents (0.5%). These 18 deaths were included in overall mortality analysis but not in cause-specific analysis. In the previous follow-up through 1980, there were 432 (6.3%) individuals whose vital status was not

TABLE II. Descriptive Statistics of a Cohort of Lead Battery and Lead Smelter Workers, USA

Description	Lead battery	Lead smelter	Total
Cohort size	4,518	2,300	6,818
Length of employment as of December 31, 1981			
< 10 years	417 (9.2%)	836 (36.3%)	1,253 (18.4%)
10–19 years	991 (21.9%)	559 (24.3%)	1,550 (22.7%)
20 + years	3,110 (68.8%)	905 (39.3%)	4,015 (58.9%)
Year of hire			
< 1946	2,571 (56.9%)	485 (21.1%)	3,056 (44.8%)
1946 +	1,947 (43.1%)	1,815 (78.9%)	3,762 (55.2%)
Vital status as of December 31, 1995			
Alive	1,710 (37.8%)	1,039 (45.2%)	2,749 (40.3%)
Dead	2,613 (57.8%)	1,100 (47.8%)	3,713 (54.5%)
With death certificates	2,600 (99.5%)	1,095 (99.5%)	3,695 (99.5%)
Without death certificates	13 (0.5%)	5 (0.5%)	18 (0.5%)
Unknown	195 (4.3%)	161 (7.0%)	356 (5.2%)

TABLE III. Observed and Expected Deaths, Standardized Mortality Ratios and 95% Confidence Intervals by Cause of Death Among 6,818 Lead Battery and Lead Smelter Workers, 1947–1995, USA

Cause of death	OBS	EXP	SMR	95% Confidence limits Lower	Upper
All causes of death	3713	3551.81	104.5**	101.2	108.0
All malignant neoplasms	897	864.17	103.8	97.1	110.8
Cancer of buccal cavity & pharynx	13	22.37	58.1*	30.9	99.4
Cancer of digestive organs & peritoneum	254	230.53	110.2	97.0	124.6
Cancer of esophagus	22	20.20	108.9	68.2	164.9
Cancer of stomach	60	40.70	147.4**	112.5	189.8
Cancer of large intestine	81	81.52	99.4	78.9	123.5
Cancer of rectum	22	23.03	95.5	59.9	144.6
Cancer of biliary passages & liver	14	16.09	87.0	47.6	146.0
Cancer of pancreas	41	44.30	92.6	66.4	125.6
Cancer of all other digestive organs	14	8.51	164.5	89.9	276.0
Cancer of respiratory system	330	286.98	115.0*	102.9	128.1
Cancer of larynx	9	11.26	79.9	36.5	151.7
Cancer of bronchus, trachea, lung	317	272.40	116.4**	103.9	129.9
Cancer of all other respiratory	4	3.21	124.6	34.0	319.1
Cancer of prostate	75	88.81	84.5	66.4	105.9
Cancer of testes and other male genital organs	0	2.93	0.0	0.0	125.9
Cancer of kidney	13	20.45	63.6	33.9	108.7
Cancer of bladder and other urinary organs	16	28.83	55.5*	31.7	90.1
Malignant melanoma of skin	9	10.53	85.4	39.1	162.2
Cancer of central nervous system	15	20.05	74.8	41.9	123.4
Cancer of thyroid & other endocrine glands	8	2.60	308.0*	133.0	606.8
Cancer of bone	3	2.96	101.2	20.9	295.8
Cancer of all lymphatic, haematopoietic tissue	74	80.28	92.2	72.4	115.7
Lymphosarcoma & reticulosarcoma	6	11.85	50.6	18.6	110.2
Hodgkins disease	8	6.14	130.3	56.2	256.7
Leukemia & aleukemia	34	33.30	102.1	70.7	142.7
Cancer of all other lymphopoietic tissue	26	29.00	89.7	58.6	131.4
Benign neoplasms	2	8.12	24.6*	3.0	89.0

*Significant at 5% level
**Significant at 1% level

determined. In the present update, the number or workers with unknown vital status was reduced to 356 (5.2%). Person-years of observation of these 356 individuals were counted up to the last known date of employment.

Site-specific cancer mortality analysis for the combined cohort of lead battery and lead smelter workers is presented in Table III. A small but statistically significant increase of overall mortality was found (SMR = 104.5, 95% CI: 101.2–108.0). Three cancer sites showed significant increases: stomach cancer (SMR = 147.4, 95% CI: 112.5–189.8), lung cancer (SMR = 116.4, 95% CI: 103.9–129.9), and cancer of the thyroid and other endocrine glands (SMR = 308.0, 95% CI: 133.0–606.8). On the other hand, significant deficits were observed for cancer of the buccal cavity and pharynx (SMR = 58.1, 95% CI: 30.9–99.4) and bladder cancer (SMR = 55.5, 95% CI: 31.7–90.1). Mortality from other cancer sites was as expected. In particular, there was no increase in mortality from kidney cancer (SMR = 63.6, 95% CI: 33.9–108.7), cancer of the central nervous system (SMR = 74.8, 95% CI: 41.9–123.4), or lymphatic and hematopoietic cancer (SMR = 92.2, 95% CI: 72.4–115.7). There were 34 deaths attributed to leukemia, with 33.30 expected (SMR = 102.1, 95% CI: 70.7–142.7). The OCMAP program did not provide separate analyses for non-Hodgkin's lymphoma (NHL) or multiple myeloma (MM). However, additional separate analyses indicated that the SMR for NHL was 73.3 (95% CI: 49.5–104.7; 22 observed deaths), and the SMR for MM was 57.7 (95% CI: 26.5–109.5; 9 observed deaths).

TABLE IV. Observed and Expected Deaths, Standardized Mortality Ratios and 95% Confidence Intervals by Cause of Death Among 4,518 Lead Battery Workers, 1947–1995, USA

				95% Confidence limits	
Cause of death	**OBS**	**EXP**	**SMR**	**Lower**	**Upper**
All causes of death	2613	2449.83	106.7**	102.6	110.8
All malignant neoplasms	624	596.05	104.7	96.6	113.2
Cancer of buccal cavity & pharynx	11	15.54	70.8	35.3	126.7
Cancer of digestive organs & peritoneum	183	161.95	113.0	97.2	130.6
Cancer of esophagus	16	13.84	115.6	66.1	187.8
Cancer of stomach	45	29.45	152.8**	111.5	204.5
Cancer of large intestine	59	56.80	103.9	79.1	134.0
Cancer of rectum	14	16.53	84.7	46.3	142.1
Cancer of biliary passages & liver	10	10.94	91.4	43.8	168.1
Cancer of pancreas	30	30.79	97.4	65.7	139.1
Cancer of all other digestive organs	9	6.18	145.6	66.6	276.3
Cancer of respiratory system	219	194.41	112.6	98.2	128.6
Cancer of larynx	7	7.81	89.7	36.1	184.8
Cancer of bronchus, trachea, lung	210	184.31	113.9	99.0	130.4
Cancer of all other respiratory	2	2.21	90.5	10.9	326.9
Cancer of prostate	54	62.93	85.8	64.5	112.0
Cancer of testes and other male genital organs	0	1.96	0.0	0.0	188.4
Cancer of kidney	7	13.95	50.2	20.2	103.4
Cancer of bladder and other urinary organs	10	20.53	48.7*	23.4	89.6
Malignant melanoma of skin	4	6.89	58.0	15.8	148.6
Cancer of central nervous system	10	13.34	75.0	35.9	137.9
Cancer of thyroid & other endocrine glands	5	1.80	277.9	90.2	648.5
Cancer of bone	2	2.11	94.7	11.5	342.1
Cancer of all lymphatic, haematopoietic tissue	53	55.06	96.3	72.1	125.9
Lymphosarcoma & reticulosarcoma	4	8.38	47.7	13.0	122.2
Hodgkins disease	6	4.18	143.5	52.6	312.2
Leukemia & aleukemia	26	23.07	112.7	73.6	165.2
Cancer of all other lymphopoietic tissue	17	19.43	87.5	51.0	140.1
Benign neoplams	2	5.51	36.3	4.4	131.0

*Significant at 5% level.
**Significant at 1% level.

Tables IV and V show cancer mortality analysis separately for lead battery and lead smelter workers. To a large extent, mortality patterns were similar between the two groups. In particular, mortality increases were observed in both groups for stomach cancer, lung cancer, and cancer of the thyroid and other endocrine glands, although some of the individual increases were no longer statistically significant because of the reduced number of deaths in separate analyses. There was no increased mortality in either lead battery or lead smelter workers for kidney cancer, bladder cancer, cancer of the central nervous system, or lymphatic and hematopoietic cancer.

Mortality analysis by hire date (<1946 vs. 1946+) for the total cohort of lead battery and smelter workers is depicted in Table VI. Mortality from stomach cancer was elevated regardless of hire date, but the increase among those hired before 1946 was significant (SMR = 142.6, 95% CI: 103.2–192.1), whereas that among those hired in or after 1946 was not (SMR = 161.3, 95% CI: 94.0–258.3). In contrast, mortality from lung cancer was significantly elevated among those hired in or after 1946 (SMR = 135.0, 95% CI: 114.3–158.3), whereas lung cancer mortality was as expected among those hired prior to 1946 (SMR = 103.4, 95% CI: 88.3–120.4). For cancer of the thyroid and other endocrine glands, nonsignificant increases of approximately the same magnitude were observed for both groups (SMR = 306.0 for those hired before 1946, and SMR = 311.4 for those hired in or after 1946). No increased

TABLE V. Observed and Expected Deaths, Standardized Mortality Ratios and 95% Confidence Intervals by Cause of Death Among 2,300 Lead Smelter Workers, 1947–1995, USA

Cause of death	OBS	EXP	SMR	95% Confidence limits	
				Lower	Upper
All causes of death	1100	1101.99	99.8	94.0	105.9
All malignant neoplasms	273	268.12	101.8	90.1	114.6
Cancer of buccal cavity & pharynx	2	6.83	29.3	3.5	105.8
Cancer of digestive organs & peritoneum	71	68.58	103.5	80.9	130.6
Cancer of esophagus	6	6.37	94.2	34.6	205.1
Cancer of stomach	15	11.25	133.4	74.6	220.0
Cancer of large intestine	22	24.72	89.0	55.8	134.7
Cancer of rectum	8	6.50	123.0	53.1	242.4
Cancer of biliary passages & liver	4	5.15	77.7	21.2	199.0
Cancer of pancreas	11	13.51	81.4	40.6	145.7
Cancer of all other digestive organs	5	2.33	214.8	69.7	501.3
Cancer of respiratory system	111	92.58	119.9	98.6	144.4
Cancer of larynx	2	3.46	57.8	7.0	208.9
Cancer of bronchus, trachea, lung	107	88.09	121.5	99.5	146.8
Cancer of all other respiratory	2	1.00	200.2	24.2	723.2
Cancer of prostate	21	25.88	81.1	50.2	124.0
Cancer of testes and other male genital organs	0	0.97	0.0	0.0	379.2
Cancer of kidney	6	6.50	92.3	33.9	201.0
Cancer of bladder and other urinary organs	6	8.30	72.3	26.5	157.4
Malignant melanoma of skin	5	3.64	137.2	44.5	320.3
Cancer of central nervous system	5	6.71	74.5	24.2	173.9
Cancer of thyroid & other endocrine glands	3	0.80	375.7	77.5	1098.0
Cancer of bone	1	0.85	117.4	2.9	654.4
Cancer of all lymphatic, haematopoietic tissue	21	25.22	83.3	51.5	127.3
Lymphosarcoma & reticulosarcoma	2	3.46	57.7	7.0	208.6
Hodgkins disease	2	1.96	102.1	12.4	368.9
Leukemia & aleukemia	8	10.24	78.2	33.7	154.0
Cancer of all other lymphopoietic tissue	9	9.57	94.0	43.0	178.5
Benign neoplams	0	2.61	0.0	0.0	141.4

*Significant at 5% level.
**Significant at 1% level.

mortality was seen in either group by hire date for kidney cancer, bladder cancer, cancer of the central nervous system, or lymphatic and hematopoietic cancer.

Mortality analysis by hire date is shown separately for lead battery and lead smelter workers in Tables VII and VIII, respectively. For stomach cancer, only lead battery workers hired before 1946 experienced a significantly higher risk (SMR = 148.6, 95% CI: 104.6–204.8), whereas for lung cancer, only lead battery workers hired in or after 1946 had a significantly elevated risk (SMR = 153.4, 95% CI: 121.3–191.5).

Mortality analysis by length of employment in lead battery and lead smelter workers is presented in Table IX. For stomach cancer and lung cancer, only those with 10–19 years of employment experienced significantly increased risks (SMR = 203.7 and SMR = 144.7, respectively). All eight deaths from cancer of the thyroid and other endocrine glands were among workers with 20 or more years of employment, resulting in an SMR of 462.7 (95% CI: 199.8–911.6). No increase in kidney cancer, bladder cancer, cancer of the central nervous system, or lymphatic and hematopoietic cancer was seen for any group by length of employment.

Table X shows cause-specific mortality analysis by latency. There were significant increases from stomach cancer among lead battery and lead smelter workers with <20 and 20–34 years of latency (SMRs of 222.2 and 160.2). Among those with a latency of 35+ years, there was a small nonsignificant increase (SMR = 118.4). For mortality from lung cancer, only workers with 20–34 years of latency

TABLE VI. Mortality Analysis by Date of Hire in Lead Battery and Smelter Workers, USA

	< 1946		1946+	
Cause of death	**OBS**	**SMR**	**OBS**	**SMR**
All causes	2472	103.9	1241	105.8*
All malignant neoplasms	547	98.3	350	113.7*
Cancer of buccal cavity & pharynx	9	62.8	4	49.8
Cancer of digestive organs & peritoneum	176	111.6	78	107.2
Cancer of esophagus	14	113.8	8	101.3
Cancer of stomach	43	142.6*	17	161.3
Cancer of large intestine	58	104.8	23	87.9
Cancer of rectum	18	107.1	4	64.2
Cancer of biliary passages & liver	12	121.0	2	32.4
Cancer of pancreas	20	68.7	21	138.1
Cancer of all other digestive organs	11	172.7	3	140.3
Cancer of respiratory system	174	102.4	156	133.2**
Cancer of larynx	6	83.0	3	74.4
Cancer of bronchus, trachea, lung	166	103.4	151	135.0**
Cancer of all other respiratory organs	2	99.8	2	165.9
Cancer of prostate	48	70.5*	27	130.3
Cancer of testes & other male genital organs	0	0.0	0	0.0
Cancer of kidney	7	56.5	6	74.4
Cancer of bladder & other urinary organs	12	55.5*	4	55.4
Malignant melanoma of skin	4	79.2	5	91.2
Cancer of central nervous system	7	67.1	8	83.1
Cancer of thyroid & other endocrine glands	5	306.0	3	311.4
Cancer of bone	2	97.5	1	109.7
Cancer of all lymphatic, haematopoietic tissue	50	99.2	24	80.3
Lymphosarcoma & reticulosarcoma	5	61.4	1	27.0
Hodgkin's disease	5	142.7	3	113.8
Leukemia	22	100.7	12	104.7
Cancer of other lymphopoietic tissue	18	106.6	8	66.0
Benign neoplams	1	19.6	1	33.0

*Significant at the 0.05 level
**Significnat at the 0.01 level

experienced a significant increase (SMR = 138.4, 95% CI: 115.4–164.7). For mortality from cancer of the thyroid and other endocrine glands, workers with 35+ years of latency had a significant SMR of 518.5 (95% CI: 190.3–1128.5).

In addition to the cohort study, a nested case-control study was also conducted at a large battery plant in Philadelphia (the largest participant in the cohort study). The nested case-control study consisted of 30 stomach cancer cases and 120 age-matched controls. The means of various lead exposure indices for the stomach cancer cases and controls are presented in Table XI. Cases had either similar or slightly lower mean exposures than the controls. However, none of the differences were statistically significant. The results of the case-control analysis of stomach cancer are summarized in Table XII. Odds ratios were calculated for each quartile of exposure category, and trend tests were also performed. There was no indication of any association between lead exposure and stomach cancer, based on either individual odds ratios (ORs) or trend test. For example, based on the total weighted cumulative exposure, the ORs were 1.00, 0.62, 0.82, and 0.61 for the lowest, second, third, and highest quartile, respectively, with a P-value of 0.47 for the trend test. On the other hand, it was noted that there were more foreign-born workers among the stomach cancer cases than among their age-matched controls (OR = 1.29, 95% CI: 0.61–3.06). In particular, 40% cases were born in Ireland or Italy, compared to only 23% controls (OR = 2.30, 95% CI: 0.99–5.36).

TABLE VII. Mortality Analysis by Date of Hire in Lead Battery Workers, USA

	< 1946		1946+	
Cause of death	**OBS**	**SMR**	**OBS**	**SMR**
All causes	2087	108.3**	526	100.7
All malignant neoplasms	458	100.0	166	120.2*
Cancer of buccal cavity & pharynx	8	67.1	3	82.9
Cancer of digestive organs & peritoneum	151	116.3	32	99.7
Cancer of esophagus	13	127.2	3	83.0
Cancer of stomach	37	148.6*	8	175.8
Cancer of large intestine	50	110.4	9	78.3
Cancer of rectum	14	101.1	0	0.0
Cancer of biliary passages & liver	9	110.6	1	35.7
Cancer of pancreas	19	79.1	11	162.6
Cancer of all other digestive organs	9	170.9	0	0.0
Cancer of respiratory system	140	99.1	79	148.5**
Cancer of larynx	6	99.9	1	55.5
Cancer of bronchus, trachea & lung	132	98.9	78	153.4**
Cancer of all other respiratory organs	2	120.4	0	0.0
Cancer of prostate	41	75.1	13	155.7
Cancer of testes & other male genital organs	0	0.0	0	0.0
Cancer of kidney	5	48.8	2	54.0
Cancer of bladder & other urinary organs	10	57.0	0	0.0
Malignant melanoma of skin	3	71.6	1	37.0
Cancer of central nervous system	5	57.1	5	109.0
Cancer of thyroid & other endocrine glands	4	294.8	1	226.2
Cancer of bone	2	117.4	0	0.0
Cancer of all lymphatic & haematopoietic tissue	42	101.4	11	80.6
Lymphosarcoma & reticulosarcoma	4	59.1	0	0.0
Hodgkin's disease	5	170.5	1	80.0
Leukemia	20	111.8	6	116.0
Cancer of other lymphopoietic tissue	13	94.1	4	71.3
Benign neoplams	1	24.1	1	73.0

*Significant at the 0.05 level.
**Significant at the 0.01 level.

DISCUSSION

Similar to the previous analysis, in the present updated cohort study there was a small increase in overall mortality for the entire cohort of lead battery and lead smelter workers (SMR = 104.5). The increase occurred among lead battery workers only (SMR = 106.7), but not among lead smelter workers (SMR = 99.8). However, in either subcohort there was no evidence for the commonly observed healthy worker effect.

In terms of specific cancers, among lead battery workers, there was a significantly elevated mortality from stomach cancer (SMR = 152.8). A slightly smaller non-significant increase was observed among lead smelter workers (SMR = 133.4). These increases in stomach cancer mortality were similar to, but somewhat smaller than those reported in the previous analysis. There was no pattern of an increase of stomach cancer by length of employment in the cohort study. In fact, the lowest SMR was observed in the group with the longest employment (20+ years).

For stomach cancer, a nested case-control study was conducted in addition to the cohort study. Jobs were classified into three categories (low, intermediate, and high) according to potential for exposure to lead. A weighted cumulative exposure index was created for each subject. No difference in terms of exposure was found between the stomach cancer cases and their age-matched controls. Furthermore, no elevated odds ratios or upward trends were reported for any exposure categories. Thus, the results from both the cohort and the nested case-control

TABLE VIII. Mortality Analysis by Date of Hire in Lead Smelter Workers, USA

	< 1946		1946+	
Cause of death	**OBS**	**SMR**	**OBS**	**SMR**
All causes	385	85.2**	715	109.9*
All malignant neoplasms	89	90.4	184	108.5
Cancer of buccal cavity & pharynx	1	41.4	1	22.6
Cancer of digestive organs & peritoneum	25	89.6	46	113.1
Cancer of esophagus	1	48.0	5	116.7
Cancer of stomach	6	114.1	9	150.3
Cancer of large intestine	8	79.5	14	95.5
Cancer of rectum	4	135.5	4	112.7
Cancer of biliary passages & liver	3	168.7	1	29.7
Cancer of pancreas	1	19.7	10	118.5
Cancer of all other digestive organs	2	180.8	3	245.6
Cancer of respiratory system	34	118.8	77	120.4
Cancer of larynx	0	0.0	2	89.6
Cancer of bronchus, trachea & lung	34	125.7	73	119.6
Cancer of all other respiratory organs	0	0.0	2	304.4
Cancer of prostate	7	51.8	14	113.2
Cancer of testes & other male genital organs	0	0.0	0	0.0
Cancer of kidney	2	93.5	4	91.8
Cancer of bladder & other urinary organs	2	49.1	4	94.7
Malignant melanoma of skin	1	116.1	4	143.8
Cancer of central nervous system	2	119.2	3	59.6
Cancer of thyroid & other endocrine glands	1	360.9	2	383.6
Cancer of bone	0	0.0	1	199.0
Cancer of all lymphatic & haematopoietic tissue	8	89.2	13	80.0
Lymphosarcoma & reticulosarcoma	1	72.8	1	47.8
Hodgkin's disease	0	0.0	2	144.2
Leukemia	2	50.6	6	95.5
Cancer of other lymphopoietic tissue	5	153.0	4	61.5
Benign neoplams	0	0.0	0	0.0

*Significant at the 0.05 level.
**Significant at the 0.01 level.

studies argued against a causal role of occupational exposure.

On the other hand, there were more foreign-born workers among the cases than among the controls, particularly for those born in Ireland or Italy (OR = 2.30, 95% CI: 0.99–5.36). Epidemiologic studies have reported a higher risk of stomach cancer among immigrants in the U.S. In a review, Howson et al. [1986] compared stomach cancer mortality rates during two time periods (1950–52 and 1977–79) among 18 countries, including Ireland, Italy, and the U.S. Although stomach cancer mortality rates declined drastically for all three countries between the two time periods, the rates for Ireland and Italy were two to four times higher than those for the U.S. during the same time periods. Based on the nested case-control study, the increase in stomach cancer mortality observed in the cohort study appeared unlikely to be related to lead exposure. On the other hand, being foreign-born might have accounted for at least part of the increase.

Likewise, results on stomach cancer from other studies of workers exposed to lead have suggested a small increase but no exposure–response relationship. Gerhardsson et al. [1986] reported a significant increase of stomach cancer mortality in a cohort of 3,832 workers exposed to lead at a copper smelter in northern Sweden (SMR = 143, 95% CI: 105–191, 46 observed deaths). In a subgroup of 437 workers with "verified high lead exposure," there was no increase (SMR = 95, 95% CI: 19–274, 3 observed deaths). The mean blood lead level in 1950 in the subgroup with high exposure was 58.2 μg/100 ml. In another small study of 664

TABLE IX. Mortality Analysis by Length of Employment in Lead Battery and Smelter Workers, USA

	< 10 years		10 – 19 years		20+ years	
Cause of death	**OBS**	**SMR**	**OBS**	**SMR**	**OBS**	**SMR**
All causes	423	99.6	542	140.3**	2748	100.3
All malignant neoplasms	101	85.8	143	129.6**	653	102.7
Cancer of buccal cavity & pharynx	0	0.0	5	150.2	8	50.5*
Cancer of digestive organs & peritoneum	24	84.1	31	107.3	199	115.0
Cancer of esophagus	3	103.2	1	35.7	18	124.2
Cancer of stomach	8	170.2	11	203.7**	41	134.0
Cancer of large intestine	6	61.2	5	53.9	70	112.1
Cancer of rectum	1	37.6	6	202.3	15	86.2
Cancer of biliary passages & liver	1	45.6	0	0.0	13	108.6
Cancer of pancreas	4	69.4	7	122.4	30	91.4
Cancer of all other digestive organs	1	95.1	1	79.1	12	193.7*
Cancer of respiratory system	51	119.9	54	139.6*	225	109.3
Cancer of larynx	1	64.9	1	64.5	7	85.7
Cancer of bronchus, trachea & lung	49	121.1	53	144.7*	215	110.1
Cancer of all other respiratory organs	1	197.4	0	0.0	3	134.3
Cancer of prostate	4	56.3	8	125.3	63	83.6
Cancer of testes & other male genital organs	0	0.0	0	0.0	0	0.0
Cancer of kidney	3	97.8	3	100.6	7	48.6
Cancer of bladder & other urinary organs	3	111.2	3	109.0	10	42.8**
Malignant melanoma of skin	0	0.0	3	148.1	6	95.9
Cancer of central nervous system	2	47.3	5	128.0	8	67.1
Cancer of thyroid & other endocrine glands	0	0.0	0	0.0	8	462.7**
Cancer of bone	0	0.0	1	215.3	2	100.1
Cancer of all lymphatic & haematopoietic tissue	5	39.3*	17	150.2	52	92.5
Lymphosarcoma & reticulosarcoma	0	0.0	1	52.7	5	61.8
Hodgkin's disease	2	118.6	1	76.2	5	159.2
Leukemia	1	20.4	8	181.2	25	104.3
Cancer of other lymphopoietic tissue	2	46.9	7	189.0	17	80.8
Benign neoplams	0	0.0	2	199.3	0	0.0**

*Significant at the 0.05 level.
**Significant at the 0.01 level.

workers at a secondary lead smelter in southern Sweden, Gerhardsson et al. [1995] reported three cases of stomach cancer, compared to 1.6 expected (standardized incidence ratio, SIR = 188, 95% CI: 39–550). In a cohort study of 1,990 workers at an Idaho lead smelter, Steenland et al. [1992] reported a nonsignificant increase of stomach cancer mortality (SMR = 136, 95% CI: 75–224). However, in the subcohort with high lead exposure, the increase was somewhat smaller (SMR = 128, 95% CI: 61–234). Finally, in a cohort of 1,388 Italian lead smelter workers, Cocco et al. [1997] reported a significant mortality deficit from stomach cancer (SMR = 49, 95% CI: 29–79) when compared to national mortality rates, but the significant deficit disappeared when regional mortality rates were used for comparison (SMR = 97, 95% CI: 53–162).

At present, a causal relationship between lead exposure and stomach cancer cannot be established based on the current data. In fact, the lack of exposure–response relationships in these studies argues against a causal interpretation. To further investigate the relationship between lead exposure and stomach cancer, additional nested case-control studies, incorporating quantitative lead exposure, personal and lifestyle information, are desirable.

With respect to lung cancer, similar to the previous analysis, a small but statistically significant increase was observed in the present update (SMR = 116.4, 95% CI: 103.9–129.9). The increase in lung cancer mortality was restricted to workers hired in or after 1946 (SMR = 135.0, 95% CI: 114.3–158.3), and no increase was seen in workers hired earlier (SMR = 103.4, 95% CI: 88.3–120.4), who

TABLE X. Mortality Analysis by Length of Latency in Lead Battery and Smelter Workers, USA

	< 20 years		20–34 years		35+ years	
Cause of death	**OBS**	**SMR**	**OBS**	**SMR**	**OBS**	**SMR**
All causes	465	148.3**	1243	130.4**	2005	87.7**
All malignant neoplasms	197	114.0	309	115.8*	481	95.6
Cancer of buccal cavity & pharynx	4	123.1	3	35.3	6	56.6
Cancer of digestive organs & peritoneum	29	112.2	87	120.0	138	104.4
Cancer of esophagus	0	0.0	10	143.0	12	108.0
Cancer of stomach	13	222.2*	22	160.2*	25	118.4
Cancer of large intestine	2	27.1*	25	107.7	54	106.1
Cancer of rectum	6	193.6	5	65.0	11	89.9
Cancer of biliary passages & liver	0	0.0	4	88.0	10	96.7
Cancer of pancreas	6	122.8	14	97.1	21	84.0
Cancer of all other digestive organs	2	130.0	7	243.6	5	122.0
Cancer of respiratory system	36	122.9	129	133.0**	165	102.7
Cancer of larynx	2	146.2	2	48.9	5	86.2
Cancer of bronchus, trachea & lung	34	124.3	127	138.4**	156	101.8
Cancer of all other respiratory organs	0	0.0	0	0.0	4	251.0
Cancer of prostate	5	161.2	16	98.3	54	77.8
Cancer of testes & other male genital organs	0	0.0	0	0.0	0	0.0
Cancer of kidney	1	39.8	2	28.5	10	91.6
Cancer of bladder & other urinary organs	4	188.2	4	54.0	8	41.5**
Malignant melanoma of skin	1	47.9	3	82.2	5	104.2
Cancer of central nervous system	4	88.7	2	25.9*	9	114.9
Cancer of thyroid & other endocrine glands	0	0.0	2	215.2	6	518.5**
Cancer of bone	0	0.0	1	94.4	2	164.7
Cancer of all lymphatic & haematopoietic tissue	9	74.5	29	121.0	36	81.4
Lymphosarcoma & reticulosarcoma	1	36.4	2	45.7	3	63.5
Hodgkin's disease	1	40.4	6	293.0*	1	61.9
Leukemia	4	84.3	13	138.0	17	88.8
Cancer of other lymphopoietic tissue	3	140.4	8	98.5	15	80.0
Benign neoplams	1	105.7	1	42.9	0	0.0*

*Significant at the 0.05 level.
** Significant at the 0.01 level.

were likely to have been exposed to higher levels of lead. Furthermore, no exposure–response relationship was evident based on length of employment analysis. The lowest lung cancer mortality (SMR = 110.1, 95% CI: 95.9–125.8) was observed among the group with the longest duration of employment (20+ years). The lack of an upward trend by length of employment further argues against a causal interpretation of the small lung cancer excess in the study.

It is impossible to draw firm conclusions regarding lead exposure and the small increase in lung cancer mortality reported in the present update. An increase of approximately 15% (such as the one in this study), in the absence of a positive exposure–response relationship between lead exposure and lung cancer, could be the result of confounding due to smoking. For example, if we assume that smoking produces a lung cancer relative risk of ten-fold in general, a 15% increase in lung cancer risk can easily be explained by a 10–15% difference in smokers between the study cohort and the comparison population [Wong and Musselman, 1994]. Unfortunately, smoking information was not available in the present investigation. However, the small magnitude of the increase and the lack of a positive exposure–response relationship in the present investigation tend to argue against a causal interpretation.

Results on lung cancer from other studies of lead exposed workers are inconsistent. For example, in the Idaho lead smelter study, Steenland et al. [1992] reported a small nonsignificant increase in lung cancer mortality (SMR = 1.18, 95% CI: 0.92–1.48) for the entire cohort. In the subcohort of workers with high exposure, the increase

TABLE XI. Comparison of Employment/Exposure Histories of Cases and Controls Based on Employment Prior to Death Dates of Index Cases

	Cases (n = 30)		Controls (n = 120)		Cases v. controls	
Employment/exposure histories*	**Mean**	**SD**	**Mean**	**SD**	**Difference**	**SD**
Months employment at the plant						
Total pre-death	275.4	149.2	302.6	138.1	−27.1	30.0
10 years pre-death	234.9	139.5	245.7	139.0	−10.8	28.5
20 years pre-death	149.5	117.1	156.1	121.3	−6.6	24.1
Months in intermediate or high exposure areas						
Total pre-death	185.8	163.0	202.0	156.8	−16.3	33.0
10 years pre-death	163.3	150.0	165.7	146.2	−2.5	30.5
20 years pre-death	108.1	110.3	108.5	117.9	−0.3	22.2
Weighted exposures						
Total pre-death	485.0	298.1	555.1	327.5	−70.1	62.1
10 years pre-death	407.3	267.7	444.8	315.4	−37.5	56.7
20 years pre-death	257.2	214.7	287.4	267.9	−30.3	46.2

*See text for a full description of exposure classification.

TABLE XII. Results of Conditional Logistic Regression Analysis in a Nested Case-control Study of Stomach Cancer Among Lead Battery Workers

	Employment at the plant			Employment in intermediate or high exposure areas			Weighted exposure		
Exposure category*	**Cases/controls**	**OR**	**P**	**Cases/controls**	**OR**	**P**	**Cases/controls**	**OR**	**P**
Total exposure pre-death									
Exposure 10 years pre-death									
Lowest quartile	10/31	1.00	–	13/30	1	–	10/30	1.00	–
2nd quartile	3/29	0.30	0.11	3/30	0.25	0.04	6/30	0.62	0.39
3rd quartile	13/30	1.70	0.34	5/30	0.43	0.14	8/30	0.82	0.72
Highest quartile	4/30	0.43	0.19	9/30	0.75	0.55	6/30	0.61	0.39
		Trend test	0.58		Trend test	0.48		Trend test	0.47
Exposure 10 years pre-death									
Lowest quartile	11/30	1.00	–	7/30	1	–	10/30	1.00	–
2nd quartile	3/30	0.03	0.07	8/30	1.13	0.84	4/30	0.39	0.15
3rd quartile	9/30	0.91	[illegible]	4/30	0.6	0.43	9/30	0.87	0.78
Highest quartile	7/30	0.68	0.55	11/30	1.73	0.34	7/30	0.61	0.45
		Trend test	0.62		Trend test	0.56		Trend test	0.74
Exposure 20 years pre-death									
Lowest quartile	10/31	1.00	–	–	–	–	8/30	1.00	–
2nd quartile	4/30	0.40	0.16	15/60	1.00	–	8/30	1.00	1.00
3rd quartile	8/30	0.81	0.73	5/30	0.66	0.45	5/30	0.61	0.47
Highest quartile	8/30	0.78	0.72	10/30	1.48	0.46	9/30	1.08	0.91
		Trend test	0.85		Trend test	0.59		Trend test	1.00

*See text for a full description of exposure classification.

was somewhat lower (SMR = 1.11, 95% CI: −0.82–1.47). Steenland et al. [1992] concluded that there was little epidemiologic evidence implicating lead exposure, and that excess smoking in the cohort might have contributed to the lung cancer increase. In the Italian study of lead smelter workers [Cocco et al., 1997], a significant deficit in lung cancer was reported when compared to national death rates (SMR = 62, 95% CI: 43–86), but the deficit was reduced when regional mortality rates were used (SMR = 82, 95% CI: 56–116). In the Swedish study of copper smelter workers [Gerhardsson et al., 1986], a significant increase of lung cancer mortality was reported (SMR = 218.4, 95% CI: 176.1–268.3) for the overall cohort, and a reduced excess for the subgroup with high lead exposure, which was not statistically significant (SMR = 160.0, 95% CI: 58.6–348.6). It should be pointed out that potential confounding due to arsenic exposure was likely at this Swedish copper smelter. In the second Swedish study of secondary lead smelter workers, Gerhardsson et al. [1995] reported a nonsignificant increase based on 6 cases (SIR = 1.32, 95% CI: 0.49–2.88).

Except for the study of Swedish copper smelter workers, lung cancer mortality increases reported in individual studies were small, and could have been due to smoking. In the Swedish copper smelter study, arsenic exposure was a potential confounding factor. Similar to stomach cancer, nested case-control studies of lung cancer, incorporating quantitative lead exposure, arsenic exposure and lifestyle (particularly smoking) information, are needed to further investigate the relationship between lead exposure and lung cancer.

In the present investigation, a significant mortality increase from cancer of the thyroid and other endocrine glands was found (SMR = 308.0, 95% CI: 133.0–606.8). Three deaths were from cancer of the thyroid gland (ICD8 193) and five from cancer of other endocrine glands (ICD8 194). All eight deaths occurred among workers with 20 or more years of employment (SMR = 462.7, 95% CI: 199.8–911.6). The highest increase was among workers with a latency of 35 years or longer (SMR = 518.5, 95% CI: 190.3–1128.5). Thus, the data seemed to suggest a potential association between employment at lead battery plants or lead smelters and cancer of the thyroid and other endocrine glands. However, it should be noted that the number of deaths was small (8), and potential confounding exposures in some of the deaths could not be ruled out. One of the known risk factors for thyroid cancer is therapeutic radiation to the head and neck for tonsillitis, eczema, acne, and thymus enlargement. Such information was not available in the present study. Furthermore, it is unfortunate that results of cancer of the thyroid and other endocrine glands have not been reported in other studies of lead exposed workers, presumably because the number of deaths from cancer of the thyroid and other endocrine glands (relatively rare cancer) was small and/or no excess was found in these other studies. As such, a comparison to other studies of lead workers was not possible.

No increase in mortality from kidney cancer, bladder cancer, cancer of the central nervous system, or any of the lymphatic and hematopoietic cancers was found in the present study. In their review and meta-analysis, Fu and Boffetta [1995] commented that the increases in kidney cancer and bladder reported in the literature could have been the result of publication bias. The only way to resolve this issue is to conduct a comprehensive meta-analysis based on data in all studies (published or otherwise). In some cases, authors may have to be contacted for data not reported in their publications.

The findings of the cohort study should be interpreted in conjunction with its limitations. One of the limitations of the study was the lack of quantitative exposure data for the entire cohort. As such, quantitative exposure–response analysis in terms of lead exposure levels was not possible. Furthermore, employment histories were truncated in 1981. For chronic diseases with long latent periods, exposure within the last decade or two before death generally has little impact on the disease. Therefore, ignoring exposure after 1981 in the analysis should have little influence on the results. In addition, information on confounding factors for some of the diseases of interest (such as diet and ethnicity in stomach cancer, smoking in lung cancer, and radiation in thyroid cancer) was not available. The collection of such personal, lifestyle or medical history data was beyond the scope of the cohort study. Some of the inadequacies in the cohort study can be alleviated by nested case-control studies, such as the one on stomach cancer reported here.

In summary, a significant mortality from stomach cancer was found in the cohort study. However, based on analyses in the cohort study and the nested case-control study, the increase did not appear to be related to lead exposure. A small, but statistically significant mortality increase from lung cancer was also observed. The small increase, in the absence of an exposure–response relationship, could be the result of confounding due to smoking, and was not likely to be causally related to lead exposure. Although the significant increase in cancer of the thyroid and other endocrine glands appeared to be consistent with an occupational interpretation, the small number of deaths, the lack of information on potential confounding factors, and the lack of reporting of a similar increase in other studies underscore the need to view this finding with caution. No increased mortality was found for kidney cancer, bladder cancer, cancer of the central nervous system, or lymphatic and hematopoietic cancer.

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APPENDIX I. Examples of Jobs by Exposure Category in the Case-Control Study

Low exposure		Intermediate exposure	High exposure
air clean tubes	mix soda	air casting	assayer
ash man	motor tender	battery man	assembly
assembly finish	mould maker	bench hand	assemble in jigs
batteries on skids	oiler	chain hoist	ball caster
blacksmith	order filler	cleaner [machine]	battery assembly
bricklayer box maker	oxygen attendant	cleaner [manual]	box plates
cable trimmer	painter/sprayer	clean up	burner assembler
car man	picking	connector burner	burning machine
carpenter	pile containers	conveyer loader	burn spines
cell filler	plug batteries	drying oven	crane follower
cell finisher	powerhouse	experimental work	crane operator
chauffeur	printer	finish grids	cut apart
checker	process inspector	finish, slam and trim	disassemble cells
clerk	process oven	floating crew	dumper
cover assembly	pump hand	floorman	feed elements
electrician	removoe saw burrs	gang boss	forming
electrolyte leveler	saw adjuster	grid caster	furnace man
elevator operator	saw fiber	grinding	grid paster
embossing machine	sawyer	helper	mill operator
emergency man	shipping	hydraulic casting machine	mixer
engineer	solderer	janitor	mix oxide
fill and finish	spray booth cleaner	laborer	paste mixer
fill batteries	switchboard	leading hand	plate burner
finisher	timekeeper	machine operator	plate cleaner
fireman	tool maker	maintenance	plate cutter
glue hand	trim castings	material handler	plate finisher
gravity and adjuster	truck repair	monorail hooker	plate handler
grid stock	unload coal	moulder	plate parter
guard	unload lumber	packer	plate paster
hardware man	vulcanizing	porter	plate wiper
instrument assembly	wash and stamp	pressman	prepare plates
jig cutter	washer	puddling grids	reclaim scrap
lead roller	watchman	punch press	saw and brush
mechanical	wax sprayer	repair batteries	saw lugs
messenger	welder	shipping machine	shaker
		supply man	shaker hand
		sweeper	skimmer
		tank man	slag man
		truck driver	
		utility	
		wireman	

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